Developments in Crude Oil Extraction and Movement

Overview

This paper examines crude oil extraction in North America and the transportation of extracted products within and through the Great Lakes basin to refineries in the United States, Canada and overseas. In the binational Great Lakes region, states, provinces and tribal governments experience both benefits and risks from crude oil transportation, in particular in light of the recent growth in oil extraction in North America. The benefits and risks vary depending on a variety of factors, such as the type and amount of oil transported, refinery location and the mode of transportation used to get the oil to its destination.

Various modes of transportation are used to move crude oil: pipeline, train, barge/tanker vessel and truck. The majority of crude oil transported in the Great Lakes basin travels by pipeline or train. Most of that oil is brought in from other locations, some of it for refining within the region, some of it en route to refineries on the east coast or along the Gulf of Mexico. Crude oil extraction does take place in the Great Lakes-St. Lawrence River region, but the quantities produced and transported are minimal compared to the quantities brought in from the Alberta oil sands and the Bakken shale formation. Vastly increased production from the latter two sources has led to an important increase in oil transportation through the basin.

Description of U.S. and Canada Crude Oil

Oil Sands Crude Oil

Oil sands (also called tar sands) crude oil is considered an unconventional type of hydrocarbon and is found in two main reserves in the world, one in Venezuela and one in Canada. There are a few much smaller reserves located in eastern Europe, Africa and the United States. In Canada, oil sands reserves are found in the western Canadian sedimentary basin, primarily in Alberta. Within this basin, oil sands are exploited in three main areas: Athabasca River, Cold Lake and Peace River.[1]

Oil sands crude is currently a significant source of revenue and is expected to remain so for years. The province of Alberta received $3.56 billion in royalties related to oil sands production in 2013.[2] Total Canadian oil and gas extraction and supporting activities generated $2.42 billion in income tax revenue to the national government in the fiscal year 2012.[3,4] During the 2010-2035 period, the oil sands production could have major economic impact in Canada (GDP impact of $2,106 billion for investment and operations) and in the United States (GDP impact of $521 billion for investment and operations).[5]

Oil sands crude, which contains more sulfur than conventional crude oil, is made up of 75-80 percent inorganic material (mostly sand and clay), 3-5 percent water and 10-12 percent bitumen, a viscous form of petroleum. Bitumen is extracted from the ground through surface mining or by in-situ recovery. Surface mining is used for deposits that are less than 250 feet below the ground's surface, mostly in the Athabasca River area. Presently, 50 percent of oil sands crude is extracted through this method, but this proportion will decline in the coming years, as only 20 percent of the reserves can be mined.[6] For reserves located deeper than 250 feet below the ground's surface, an in-situ

extraction method is used: Bitumen is recovered by injecting steam, either through steam-assisted gravity drainage (by using a pair of horizontal wells) or through cyclic steam stimulation (using a single vertical well and a three-phase cycle of steam injection, a "soak phase" which allows heat from the steam to thin the oil, and then pumping the oil to the surface).[7] Other techniques – vapor extraction, firefloods and cold production – are in development and may be used in the future.

Due to its high viscosity and density, bitumen must be processed to make transportation easier and more efficient. The most common techniques are upgrading, dilution or a combination of the two.[8] Upgraded bitumen – called synthetic crude oil (SCO) – is the product of turning the very heavy bitumen into a lighter material by separating the fractions via hydro-processing (adding hydrogen) or via coking (removing the carbon and then treating the product with hydrogen to stabilize it). Diluted bitumen –"dilbit" – is bitumen mixed with a diluent that makes it less viscous and lighter, thus easier to transport. The diluent is typically a natural gas condensate and typically makes up 25-30 percent of the total product volume. The third type of processed bitumen, synthetic bitumen or synbit, is made by combining bitumen with synthetic crude oil, usually 50 percent bitumen and 50 percent SCO. This product more closely resembles conventional crude oil in terms of its transportation characteristics.

Other methods can also be used to reduce the impacts of high viscosity. To reduce the viscosity, the pipeline or tank car can be heated (this requires more energy and can increase the possibility of internal corrosion) or the emulsification technique (oil-in-water, water-in-oil or double emulsion) can be used. To minimize the friction, drag-reducing agents (polymers, fibers or surfactants) can be added or the core-annular flow method (surrounding the crude oil with a film of water or solvent near the pipe wall) can be chosen.[9,10]

Once oil sands crude has been processed, the product is transported to refineries, usually by pipeline.[11] However, increases in production have outpaced expansion of capacity in the pipeline network, motivating oil sands producers to consider and utilize other modes of transportation, such as trains and barges.[12] Trucks are sometimes used, but mostly for onsite movement of the product or for transportation of small volumes.

Shale Crude Oil

Shale oil, also called "light tight oil," is a type of non-conventional crude oil found in low permeability sedimentary formations.[13] The physical characteristics of shale oil can vary from one formation to the other, even in the same oil field.[14,15] Recent events have raised concerns about the safety of this type of crude. Shale oil is a light crude oil that is much more volatile than other types of crude oil and has a flash point that resembles that of gasoline, making it very flammable and explosive. [16,17,18] According to several reports, DOT-111 tank cars are not appropriate for Bakken crude oil transportation. However, some industry reports concluded that the physical properties of Bakken crude oil doesn't make it more explosive or flammable than other similar products transported by rail and that the tank cars currently used (DOT-111 tank cars) are adequate.[19,20]

There are several formations of shale oil that are particularly relevant to the Great Lakes,[21] the largest being the Bakken-Three Forks formation in the Williston basin, a large basin that covers 300,000 square miles across North Dakota, South Dakota, Montana, and the provinces of Saskatchewan and Manitoba.[22] In the United States, a large amount of the shale oil production comes from North Dakota. There are several other oil-producing shale formations in the United States, including the Niobrara in Colorado, Eagle Ford in Texas, and Avalon in west Texas and southern New Mexico. In the eastern Great Lakes region, there are oil reserves in the northwestern part of the Utica-Point Pleasant formation in Ohio, Pennsylvania and New York, with a sweet spot in east central Ohio.[23] There is also marginal shale oil production in northern Michigan, in the Antrim formation.

In North Dakota alone, the Bakken shale oil industry (exploration, extraction, processing, transportation) had an estimated impact of $30.4 billion on the state's economy in 2011.[24] Shale oil is extracted through hydraulic fracturing, also known as fracking. To release the oil trapped in the rock, a mixture of water, gas and chemicals is

injected at high pressure in the rock through a horizontal well. The released oil is captured by the well and sent to the surface. It is then transported through a gathering line to a storage facility, and then transferred to a transmission pipeline or a rail tank car for transportation to refineries.

The volatility of this type of crude has raised some concerns. To reduce the volatility, gases (methane, propane, butane, hydrogen sulfide) have to be removed from the crude oil. There are several techniques, each of which has pros and cons.[25] The first technique, crude oil stabilization, involves different types of processes that will make the dissolved gases vaporize and separate from the oil. Building stabilization plants is very costly and could take several years. The second method is crude oil conditioning, a multi-step process that removes gases and water using various temperature treatments. The issues with this method are related to the extreme temperature changes in North Dakota (from well below 0°F during the winter to over 100°F in the summer). Finally, there is crude oil separation, where crude oil is processed through a large vessel designed to separate production fluids into their constituent components of oil, gas and water. It is the least costly method, but also the least efficient.

Crude oil production increased dramatically over the past 10 years, especially shale oil production. Bakken shale oil production was a little over 1 million barrels in 2005 but rose to almost 300 million barrels in 2013.[26] Oil sands crude production has also been increasing, growing from 352,000 barrels in 2005 to 708,000 barrels in 2013.[27] During that period, the pipeline network became saturated and alternative modes of transportation had to be used. In the United States, from 2011 to 2012 alone, there was a 53 percent increase in the volume of crude oil transported on waterways and a 38 percent increase in the volume transported by truck[28]. The most dramatic increase has been in rail transportation, however, where there was a 423 percent increase in the United States in that one year. In Canada, transportation by rail has also seen huge growth, from 500 carloads in 2009 to 140,000 carloads in 2013, a 28-fold increase.[29]

Oil Drilling in the Great Lakes

Oil deposits exist under portions of the Great Lakes and could be tapped using either offshore drilling on the lakes themselves or directional drilling from onshore facilities. Concerns over oil pollution risks have gradually led to complete bans on offshore drilling throughout the lakes and tight restrictions on directional drilling in many areas. In 1985, the governors of the eight Great Lakes states signed a *Statement of Principle Against Oil Drilling in the Great Lakes*.[30] This was a non-binding agreement, but all of the states viewed it as prohibiting offshore drilling and all but Michigan viewed it as prohibiting directional drilling.

Since that statement was signed, formal laws and regulations have been put in place in several states that do in fact ban offshore drilling and that ban or limit directional drilling.[31] New York and Wisconsin have laws in place that expressly prohibit drilling for oil under the Great Lakes. In Michigan, permits for new wells cannot be issued but wells in operation prior to 2002 are allowed to continue. One such well is still operating. In Ohio, drilling is prohibited under an executive order issued by the Governor. Illinois, Indiana and Minnesota do not have formal bans in place, but the in-basin portions of these jurisdictions are either small and subject to a number of restrictions that would make drilling difficult or located over areas with limited oil deposits. Pennsylvania law allows drilling under the lakes, but access to the lakes is limited and no such operations exist.[32]

At the federal level, the U.S. Energy Policy Act of 2005 forbids the issuance of permits for any new oil leases, eliminating the possibility of new drilling sites of any type in the U.S. but allowing directional drilling from onshore facilities that were already operating under permits issued prior to adoption of the Act. Again, one such operation exists in Michigan. In Canada, directional drilling is allowed and does take place, primarily under Lake Erie.[33]

Description of Movement and Logistics of Crude Oil

Transportation of crude oil can be influenced by two main considerations: differences in crude oil characteristics and differences the ability of facilities to refine each type of crude oil.[34] Historically, the United States and Canada have been importers of crude oil,[35] largely from overseas sources. For this reason, most of the U.S. and Canadian refineries are located on the coasts where ocean-going tankers can access them.[36] According to the Canadian Association of Petroleum Producers,[37] as of June 2014, there are 17 refineries in Canada. Sarnia, Montréal/Québec City and Edmonton are the three principal refining centers, but there are also facilities in the Maritimes and in British Columbia. According to the Energy Information Administration, as of January 1, 2014, there are 139 refineries in the United,[38] 18 of which are in the Great Lakes states.

Bitumen extracted from the Alberta oil sands is shipped by pipeline to the Canadian and American east and west coasts, the Gulf Coast, the Midwest, and the Great Lakes region. Approximately 70 percent of the oil sands production is sent to refineries in the Midwest.[39] In 2009, there were 26 facilities equipped to process this type of crude oil in the Midwest, 12 of them in the Great Lakes states.[40] The increased production in Alberta has been the impetus for several new projects. The Enbridge 9 pipeline reversal project from Sarnia, Ontario, to Montréal, Québec, is now in its final phase.[41] When completed, it will allow the transportation of crude oil to Montréal, where it will be either refined or shipped by tanker to a refinery in Québec City. The TransCanada Keystone XL project would enable the transportation of crude oil from the Fort McMurray region in Alberta to refineries in Montana and Oklahoma. As of beginning of February 2015, the project has been approved by both U.S. Congress and U.S. Senate and is awaiting presidential approval. TransCanada is also planning on converting the Energy East pipeline from a gas to an oil transportation line that would bring the crude oil from Alberta to Cacouna, Québec, to be exported by tanker. Another exportation project is the Kinder Morgan TransMountain pipeline (Alberta to the Canadian west coast). Lastly, there is a project that would involve the transportation of bitumen by train from Alberta to the port of Belledune, New Brunswick, from where it would be exported. While these projects are being evaluated, the industry has to rely on other modes of transportation, mostly train. The main carriers involved with oil sands transportation are Canadian National (CN), Canadian Pacific (CP), Burlington Northern Santa Fe (BNSF), Union Pacific (UP) and CSX Transportation.[42]

Most of the crude oil from the area underlain by the Bakken formation was originally transported by pipeline. However, the combination of increased production of shale oil and increased production from the Alberta oil sands has resulted in volumes of oil needing to be transported that exceed the capacity of the existing pipeline network. According to a 2012 estimate provided by the North Dakota Pipeline Authority,[43] 58 percent of Bakken crude was transported by rail, 32 percent by pipeline, 8 percent was refined on site, and 2 percent was transported by truck to Canadian pipelines.

A large amount of the Bakken crude oil is transported by rail from the extraction sites to refineries able to refine this type of oil on the U.S. east, west and Gulf coasts.[44] Some facilities in New Jersey and Pennsylvania have the infrastructure to unload the oil directly from trains. In other cases, the crude oil has to be transferred onto a barge first, usually in Albany, N.Y., and transported on water to the refinery.[45] Routes for these trains go either through the northern part of the Great Lakes states or the southern part of Ontario and Québec, travelling along Lake Champlain. A study is underway for a proposed terminal expansion at the port of Albany that would allow an increase in the amount of Bakken crude oil that is transported by train from North Dakota to Albany. Trains carrying Bakken crude oil also transit through Canada to Montréal and east coast refineries. Some crude oil is transported to Texas by train, pipeline, barge or a combination of these,[46] after which it is transported by tanker via the Gulf of Mexico, Atlantic Ocean, Gulf of St. Lawrence and St. Lawrence River to a refinery in Québec City.[47]

Rail

Crude oil can be transported by unit trains – trains where all the cars are transporting the same commodity and are going to the same destination – or by mixed trains – trains that can carry several kinds of goods with an arrangement that can change as cars are added or removed based on the destination of the goods. The volume of oil moved by either method varies, but can range from a few cars in a mixed train to 100 or more cars in a unit train.[48] Crude oil is transported in Class 111 tanks cars, commonly called DOT-111 cars, which are unpressurized cars made of 7/16 inch-steel plate. [49] The design of these cars has been criticized in government reports from both countries as out of date and insufficient for transportation of crude oil with characteristics of Bakken crude. There are seven class I railroad[50] companies in North America. The main one, Burlington Northern and Santa Fe Railway (BNSF), transports approximately 70 percent of the crude oil moved by rail, mainly from North Dakota.[51]

There are three types of railroad terminals: upstream, midstream and downstream. Upstream terminals are terminals where the oil is loaded onto railroad tank cars. Downstream terminals are the endpoint, where oil is unloaded at refineries. In between, midstream terminals are intermediate terminals where oil is unloaded from the train but transferred to pipelines or barges for the next leg of the trip.[52] The biggest concentration of upstream terminals is in North Dakota. Crude oil from this region represents up to 80 percent of total North American volume of crude transported by rail.[53]

There are 188 rail terminals in Canada and United States, and 33 of them are expanding in response to the increase in crude oil transportation. Another 51 terminals are presently under construction or planned. In the basin, there are three major operating terminals[54] [Woodhaven (MI), Toledo (OH) and Montréal (QC)] and one under construction [Chicago (IL)]. Three of these terminals are (or will be) adapted for "light tight" oil: Chicago, Woodhaven and Montréal. The one in Toledo is adapted for both "light tight" oil and bitumen from oil sands. The Woodhaven and Toledo terminals, and eventually the Chicago terminal, are unloading midstream terminals. The Montréal terminal and the St-Romuald terminal (near Québec City, just outside the limits of the basin) are both unloading downstream terminals.

Bakken crude oil is transported by rail on several railroads throughout the Great Lakes-St. Lawrence basin. The major railroad companies are BNSF and Union Pacific (UP) in the western portion of the basin, Canadian National (CN) and Canadian Pacific (CP) throughout the basin in both the United States and Canada, and CSX in the eastern part of the basin.[55] There are also some class II and class III railroad companies transporting crude oil in the basin like the Montréal, Maine & Atlantic Railway Company that was involved in the Lac-Megantic accident in July 2013.[56] As mentioned above, there are refineries in the basin equipped to handle "light tight" oil, but most Bakken crude oil being moved in the basin is being transported from the North Dakota extraction sites by rail and then by barge or tanker to refineries on the coasts of Canada and the United States.[57]

Ship and Barge

Crude oil can be transported on water by tankers – deep-water ships designed for ocean transportation – or barges – flat-bottomed vessels that often require a tug boat for propulsion.[58] Two or three river barges can be tied together, increasing the amount of oil being transported and thus increasing the volume of crude oil transported in a single trip. Coastal barges are designed for open sea, and have a much greater capacity than river barges. Even though they are slower and less efficient than tankers, they require fewer crew members and are often chosen over tankers.[59] Barges are often favored by transporters because of the smaller crew requirement.

In the United States, the inland waterways used for crude oil transportation lie outside the Great Lakes basin, but the Mississippi River, the Ohio River and the Hudson River are important parts of the region as a whole.[60] Ocean transport is used for exporting and importing crude oil and petroleum products, and also for domestic transportation from extraction sites to refineries. In Canada, the St. Lawrence River is the principal route for water transportation

on the eastern side of the country. Imported crude oil has been transported to Québec refineries for years, but this situation is now changing, as oil sands crude has started to be exported through the river, too. Since July 19, 2014, Suncor has been sending oil sands crude by rail to the Sorel-Tracy terminal (near Montreal, QC), where it is stored. On September 24, the first tanker containing oil sands crude left the port of Sorel-Tracy for a refinery in Italy. According to Suncor, there could be between one and three tanker shipments every month in the coming years. There is no crude oil presently transported by vessel on the Great Lakes, and no vessels operating on the Great Lakes currently are equipped to transport crude oil. However, with the increased production of crude oil in Canada and the United States, the traditional overland modes of transportation are challenged to meet demand. In order to move crude oil to the Great Lakes and eastern refineries faster, a project was recently proposed to build a loading dock on Lake Superior, near Superior, Wisconsin.[61] In December 2013, the application was dismissed by the Wisconsin Department of Natural Resources due to of a lack of information. Another permit application was filed in August 2014, but the refinery associated with the project has withdrawn their permit application for an oil loading facility.

Pipeline

Pipelines are the traditional mode of transportation for petroleum products and gas. In Canada, there are three major pipeline companies that transport oil sands products, but also carry some shale oil from the Bakken formation: Enbridge, TransCanada and Kinder Morgan.[62] In the United States, there are interstate pipeline companies and several smaller regional companies.

Pipelines move oil by a series of pumping stations situated along each pipeline with remotely controlled valves.[63] Different types of crude oil from different origins and with different characteristics can be transported in the same line. These different products transported in the same line are called batches. Sometimes, the batches can be separated by plugs called pigs, but most of the time this does not occur. Instead, pipeline operators separate the batches by maintaining a certain flow that will stop them from intermingling. The cleaning and inspection of pipelines are both essential to maintaining the integrity of the network and reducing the risks of incidents that could result in oil spills.

Enbridge is the major pipeline company operating transmission lines in the Great Lakes basin.[64] The Lakehead System transports oil from Alberta to Superior, Wis. From there, pipelines reach Sarnia, Ontario, either through the Straits of Mackinac or via Chicago and southern Michigan. From Sarnia, lines run east toward Hamilton, Ontario, where one line goes south toward Nanticoke and another runs south to Buffalo, N.Y. One line runs from Sarnia to Montréal, Québec. The Enbridge lines carry both oil sands crude and also some crude oil from the Bakken formation, mostly from North Dakota to the Lakehead System. Other companies are also present in the basin. If the conversion project for the Energy East line from TransCanada is approved,[65] there would be crude oil transported on the north shore of Lake Superior and Lake Huron, as well as on the shore and under the St. Lawrence River.

Truck

Individual tank trucks hold less oil than other modes of transportation (200-250 barrels for an individual tank truck, vs. 700 barrels for a rail car, which is almost always moved as part of a much larger string of containers[66]). As a result, tank trucks are predominantly used for local transportation of crude oil, usually from the extraction site to pipeline or rail loading stations. In locations where the extraction site and the refineries are in close proximity, such as in Texas, trucks are used more often.[67]

Discussion

Oil production has a major economic impact in the United States and Canada. The Great Lakes-St. Lawrence River region is an important hub for this industry in North America. There are several refineries located in the region. A

large quantity of crude oil from Alberta and North Dakota moves into or through the region every day via pipelines and railroad. Transportation on the lakes themselves via tankers and barges might become a reality in the future.

Most of the crude oil being moved in the Great Lakes-St. Lawrence River region is extracted in North Dakota and Alberta. The crude oil from the Alberta oil sands is mostly transported by pipeline through the region, and a large quantity of it is refined around the Great Lakes themselves and, soon, on the shore of the St. Lawrence River. A great proportion of crude oil from the Bakken formation, on the other hand, passes directly through the basin on its way to refineries in other regions.

Even though the physical characteristics of oil sands and shale oil differ markedly, both have the same United Nations (UN) classification (UN1267 – crude oil).[68] This single classification gives very broad criteria and restrictions for transportation despite any physical differences, indicating that more studies are needed to fully understand the potential problems and regulatory needs arising from each type of oil. The physical characteristics of both types of crude oil present different issues for everyone involved with the transportation, from the carriers to the legislators. Additional issue briefs will explore these challenges and the impacts of oil transportation for the Great Lakes-St. Lawrence River region.

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[40] According to https://web.archive.org/web/20140630141852/http://www.environmentalintegrity.org/news_reports/documents/RefineryDabaseWEB-010810.pdf
[41] Line 9 was initially flowing from west to east but this flow was reversed in 1998 because cheaper crude oil was imported from Africa and the Middle East. The increase in Alberta production lowered the price and Enbridge asked for another flow reversal. The reversal of the first part (9A from Sarnia to Westover, Ontario) is already approved and the second part (9B from Westover to Montréal, Québec) is almost approved. See http://www.enbridge.com/~/media/www/Site%20Documents/Delivering%20Energy/Projects/Line9/Line9BrochureEN.PDF for complete project description.
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[55] See map in the report available at https://www.aar.org/keyissues/Documents/Background-Papers/Crude-oil-by-rail.pdf.
[56] On July 6, 2013, a train carrying crude oil from the Bakken formation derailed in Lac-Megantic, Québec, and exploded. There were 47 deaths and the heart of the town was destroyed. Crude oil was also spilled in the Chaudiere River, which provides drinking water to thousands of people downstream.
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[58] John Frittelli *et al*. *U.S. Rail Transportation of Crude Oil: Background and Issues for Congress*.
[59] Ibid.
[60] See the U.S Energy Mapping System at http://www.eia.gov/state/maps.cfm.
[61] Elkhorn Industries, a company based in Superior, Wis., wants to upgrade its dock in Superior. Calumet Specialty Product Partners could be a partner in the project and use the terminal to build a loading facility to ship crude oil from Alberta over the Great Lakes to refineries on the lakes or eastern ??.
[62] See the information provided by the U.S. Energy Information Administration at http://www.eia.gov/countries/analysisbriefs/Canada/canada.pdf.
[63] Committee for a Study of Pipeline Transportation of Diluted Bitumen, Transportation Research Board, Board on Energy and Environmental Systems, Board on Chemical Sciences and Technology, National Research Council. *TRB Special Report 311: Effects of Diluted Bitumen on Crude Oil Transmission Pipelines*. (National Research Council, 2013).
[64] See the information available on the Enbridge website at http://www.enbridge.com/DeliveringEnergy/OurPipelines/LiquidsPipelines.aspx.
[65] See the project description on the TransCanada website at http://www.transcanada.com/energy-east-pipeline.html.
[66] John Frittelli *et al*. *U.S. Rail Transportation of Crude Oil: Background and Issues for Congress*.
[67] Ibid.
[68] Transportation of Dangerous Goods General Policy Advisory Council (GPAC) of Canada – Testing and Classification Working Group. *GPAC Testing and Classification Working Group Submission and Recommendations: Strengthening the Testing and Classification Framework for Crude Oil by Rail*. (Transportation of Dangerous Goods General Policy Advisory Council (GPAC) of Canada, 2014).